Dual-frequency altimetry for precipitation and wind studies

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The planned Jason altimeter will, like the TOPEX altimeter, interleave the nominal Ku-band (2.1 cm) with a C-band (5.5 cm) signal.
The primary purpose of the second radar is to provide a collocated ranging measurement to correct for ionospheric path delay in the Ku-band range estimate.
Our research plan, which is a direct continuation of the studies undertaken by the proposing team, will further emphasize the capabilities of dual-frequency measurement in two other fields: to study oceanic precipitation and to refine the near-surface wind speed. The available TOPEX data set will be extensively used prior to the Jason launch to initiate the studies.

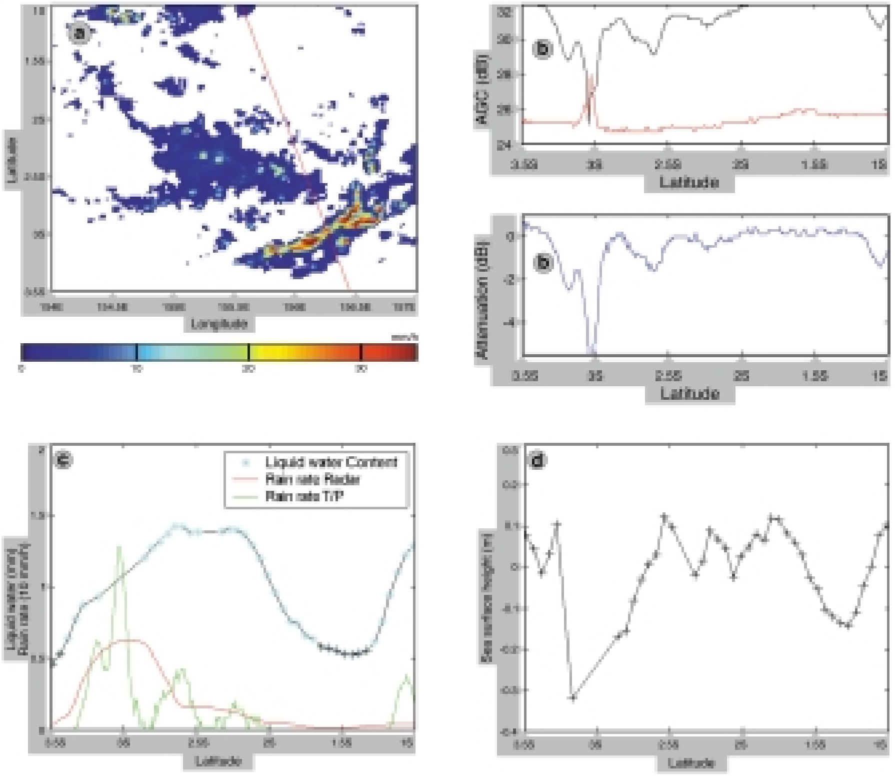

Figure 1: Impact of rain on Ku- and C-band TOPEX altimeter data. (a) Rain field (mm/h) from the MIT rain radar at 17:31 UT December 12, 1992, TOPEX ground track (red line) pass 86, cycle 10, December 12, 1992 17:16 UT. (b) top: Automatic gain control in Ku (black line) and C (red line) band. Note the strong attenuation of the Ku band near 3°S associated with rain rates over 25 mm/hr. (b) bottom: the attenuation of Ku band versus C band shows several rain cells. (c) Liquid water content (L_z) estimated from the TOPEX microwave radiometer (mm). It is generally assumed that rain is present for $L_z > 0.6$. Average rain rate from the MIT radar in a 25-kilometer-wide swath along the satellite track and estimate of rain rate by inversion of the Ku band attenuation. (d) Sea surface height. Even if the majority of the samples within rain cells are flagged, it can be seen that the distortion of the altimeter waveforms affects the retrieval of geophysical parameters.

Scientific and technical program

The Jason altimeter will operate at two microwave frequencies, 13.5 GHz (Ku-band) and 5.3 GHz (C-band). The primary goal of the dual-frequency operation is to provide a precise ionospheric correction. Besides a differential ionospheric path delay, Ku- and C-band signals are differentially and significantly affected by geophysical quantities such as atmospheric precipitation and sea surface roughness. The potential benefit of having collocated measurements of surface backscatter at two frequencies to infer atmospheric liquid water and near-surface wind has been investigated in recent years using the TOPEX data.
The promising results of these studies encourage us to carry on and develop the ongoing research effort on the analysis of dual-frequency measurements.
The program covers two themes: first, the analysis of the impact of precipitation and estimation of rain from altimetry, and second, the refinement of near-surface wind algorithms.

Impact of precipitation

Besides others effects, raindrops absorb the altimeter pulse and attenuate the return pulse power. This attenuation, which is frequency-dependent, is an order of magnitude larger in Ku than in C-band. The C-band is only slightly attenuated, except in heavy rain. Furthermore, when an altimeter footprint is partially filled by rain, the surface echo (waveform) received by the altimeter is distorted.
This causes problem in altimeter processing and errors in both sea surface height and significant wave height estimates [Quartly et al., 1996, Tournadre, 1998]. For the TOPEX altimeter, a rain flag has been proposed using a simple criterion based on the detection of a simultaneous departure from the normal C-Ku backscatter relationship and an excess of liquid

vapor content as estimated from the TOPEX Microwave Radiometer (TMR) [Tournadre and Morland, 1997].

Using a precipitation index based on similar criteria, global monthly rain climatologies have been estimated from TOPEX altimeter data [Chen et al, 1997]. They show a good qualitative and quantitative agreement with those obtained from in-situ or other satellite data. Moreover, attempts to determine rain cell characteristics from waveform analysis have been made to obtain a high-resolution description of the rain distribution under various weather conditions.

These investigations will be carried on using Jason data to further assess rain climatologies, to determine rain cell characteristics and to test rain flags from altimetric missions.

1. The rain flag based on the Ku-C relationship will be validated during the calibration/validation phase and the impact of the rain flagging on the accuracy of the mean surface topography will be tested on selected regions.

2. Seasonal rain climatologies will be constructed using TOPEX and Jason data as well as ENVISAT dual-frequency (Ku and S band) altimeter data. Particular attention will be paid to intercalibration of the fields during the overlap period.

3. Based on an analytical model, a method has been defined to invert the altimeter waveform distortion in terms of rain cell characteristics (rain rate, diameter) (see figure 2). This allows a precise description of rain fields in tropical cyclones, for example. The method will be further tested and validated to produce rain cell characteristics climatology.

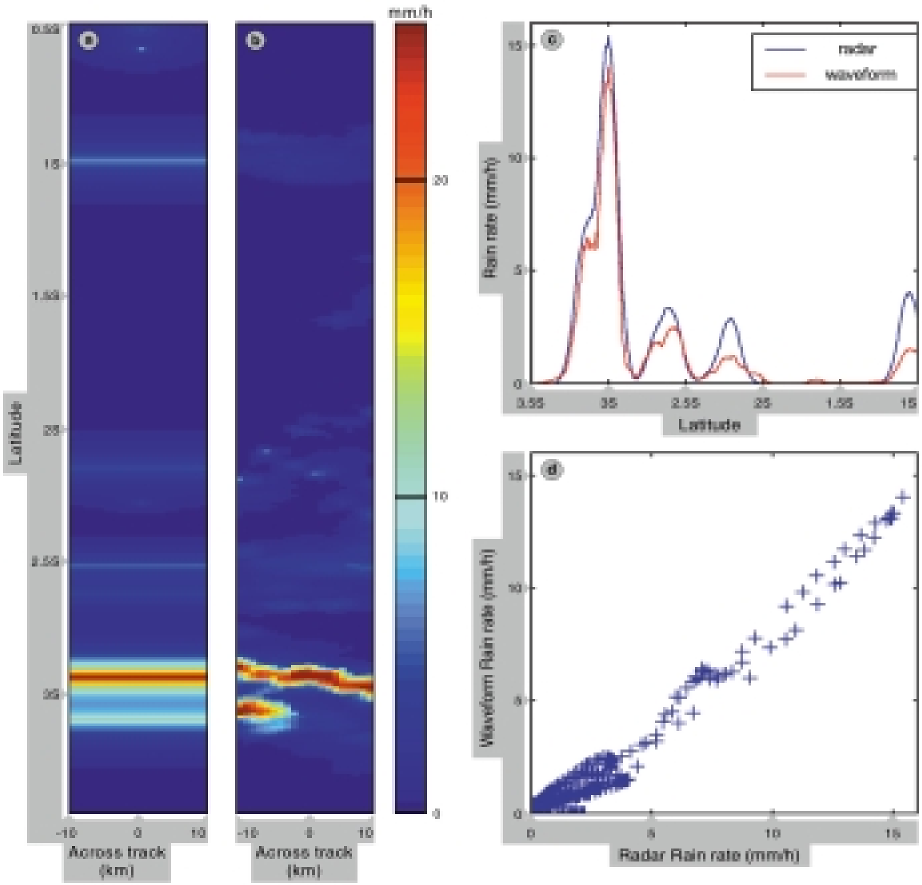

Figure 2: Comparison of rain estimates from waveform analysis and rain radar. (a) rain rate field in a 20-kilometres-wide swath (corresponding to the altimeter footprint) along the satellite track. (b) MIT radar rain field within the same swath as (a). (c) Average rain rate computed from the rain field in (a) and (b). (d) Scatterplot of rain rate estimates from waveform analysis and rain radar.

Near-surface wind speed refinement

A mono-frequency altimeter's measurement of ocean radar cross section can be mapped directly onto an estimate of surface wind speed. The most widely used algorithm is the Modified Chelton and Wentz look-up table [Witter and Chelton, 1991]. This empirically-derived routine was developed through comparisons with buoy wind measurements. It provides an estimate of wind speed at 10 or 19.5 metres above the surface.
For such nadir-looking backscatter measurements, studies of physically-based ocean scattering models have shown that a more direct altimeter inference can be made in terms of filtered surface mean square slope (mss). This parameter parallels the classical optical measurements of ocean mss versus wind speed obtained by Cox and Munk [1954]. It has also been shown that additional attenuation of nadir cross section can be associated with the spectral density of short gravity-capillary waves. This impact needs

to be considered when defining an effective reflection coefficient [Jackson et al, 1992].

The importance of such altimeter studies is that, while short waves on the sea surface are the roughness elements responsible for microwave backscatter changes, they also determine to a large extent the air-sea transfer processes (which are of importance for climate studies). As a consequence, radar backscatter measurements will be highly correlated to the wind friction velocity [Elfouhaily et al., 1997].

However, the ocean surface is nominally constituted of both local wind-waves and swell-waves, generated elsewhere, that have propagated into the area of interest. Both systems of waves will influence altimeter radar returns either by affecting the slopes of the wave field or by modulating the gravity-capillary wave frequency and amplitude. Long gravity waves can also influence the wind profile to enhance small-scale amplitude variations along the long-wave phases.

The potential of using dual-frequency altimeter measurements to directly assess sea surface small-scale roughness has been proven [Elfouhaily et al, 1997]. Indeed, these data help provide evidence of non-wind impacts, such as residual sea state, on mono-frequency altimeter wind estimates. Now, these observations and a composite model of surface altimeter backscatter are being used to define an altimeter surface roughness parameter. This parameter can then be tentatively compared with the aerodynamic roughness length commonly used to describe the stress of the wind on the ocean surface [Elfouhaily et al., 1998].

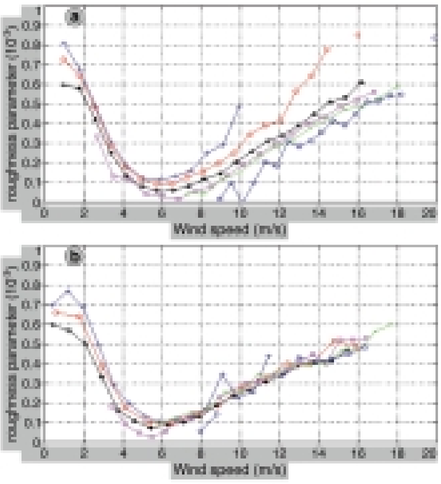

Figure 3: Surface roughness parameter estimated from Ku-C band difference as a function of altimeter Ku-band inferred wind speed (Modified Chelton and Wentz algorithm) for different range of significant wave heights (a), roughness parameter as a function of NSCAT wind speed estimates. Only NSCAT incidences higher than 40° are considered (b).

Taking the opportunity to compare our derived surface roughness parameter with the NSCAT scatterometer wind speed estimates, the analysis shown in figure 3 suggests that we can expect to achieve considerable improvement by using dual-frequency altimeter measurements.

Furthermore, we feel that it is crucial to define the relative weighting scattering from large- and small-scale structures on the electromagnetic (EM) bias versus wind speed and sea state. We believe that the respective influences can be documented by using multiple comparisons between dual-frequency altimeter measurements and scatterometer ones (ERS-1/2, NSCAT). We also intend to demonstrate through modeling and existing observations a quantitative link between satellite scatterometer upwind/downwind asymmetry and altimeter EM bias.

References

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